The Role of Individual Differences in Choice of Strategy and Performance in a Computer-Based Task

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Submitted to:

Naval Research Laboratory
Washington DC

Contract: N00014-94-1-G007/P00001

June 1995

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Abstract

Past research using different learning tasks has consistently shown different performance strategy patterns for field independent and dependent individuals. This research has shown that different computer environments affect how well individuals learn and that learning is dependent upon an individual's cognitive style (Morrison & Noble, 1987; MacGregor, Shapiro, & Niemiec; 1988). Other research has shown that there are individual differences (in cognitive ability, perceptual speed, and performance on a noun-pair task) in learning and executing computer tasks, specifically with regard to the type of interaction individuals choose to use (Schmidt-Nielsen & Ackerman, 1993). The present study is an attempt to correlate field dependence with performance strategies when using a specific task, the SigmaPlot graphing task. Field dependency, as measured by scores on the Group Embedded Figures Test (GEFT) (Witkin, 1971), was correlated with the mean time to complete a graph. Contrary to previous findings, field dependency was not correlated with performance. However, it was found that years of computer experience, perceptual speed, and cognitive reasoning ability were.

INTRODUCTION

When an individual performs a computer task, there are different strategies available to complete the task. The strategy an individual selects appears to be consistent over a broad range of tasks. Further, individual differences in cognitive and perceptual abilities appear to affect the types of strategies chosen by users (Meng & Patty, 1991; MacGregor, Shapiro, & Niemiec, 1988; Canino & Cicchell, 1988; Ackerman, 1988; Morison & Noble, 1987; Coventry; 1989).

Using a computer interface requires learning the components of the interface. Many systems available today have a variety of interaction modes/input devices such as the mouse and the keyboard. Even within the keyboard, there is usally more than one way to perform a given function. Some of these methods are more efficient than others. For example, using a mouse-driven menu system is typically less efficient than using function keys (Schmidt-Nielsen & Ackerman, 1993; Card, Moran, & Newell, 1983). Mouse-driven menu systems generally require that the user wait for the screen to refresh itself before continuing with the next part of a function, whereas function keys and other short-cuts allow the user to work ahead of the screen, thereby reducing the time it takes to complete a task. The keyboard also allows users to spend less time moving their hands and more time working on a given task.

Individual Differences

Ackerman (1988) has found that skill acquistion, across a variety of tasks, is dependent upon individual differences. His theory is based on that of Fleishman (1972) who proposed that there is an association between performance during practice and cognitive abilities. More specifically, Fleishman propses that general cognitive abilities determine intial task performance, perceptual-motor abilities determine performance in larger degrees later in practice, and some other task-specific ability (that differs from cognitive abilities and perceptual speed) develops with practice.

From this research, Ackerman (1988) formulated a theory of skill acquisition in which there are three phases of task performance. This theory is illustrated in Figure 1 which shows that skills are acquired through task practice as practice leads to transitions (without breaks) from Phase I to Phase III.

Phase I involves the initial learning of a task, which involves a high demand on the cognitive-attentional system. This phase is determined by general cognitive ability. Phase II is characterized by consistent practice that leads to performance speed and accuracy improvements and cogntive-attentional demands are decreased. The second phase is determined by perceptual-speed abilities. In Phase III, the task has become automated and attention can be devoted to other tasks at the same time. Psychomotor skills are be related to this asymptotic performance.

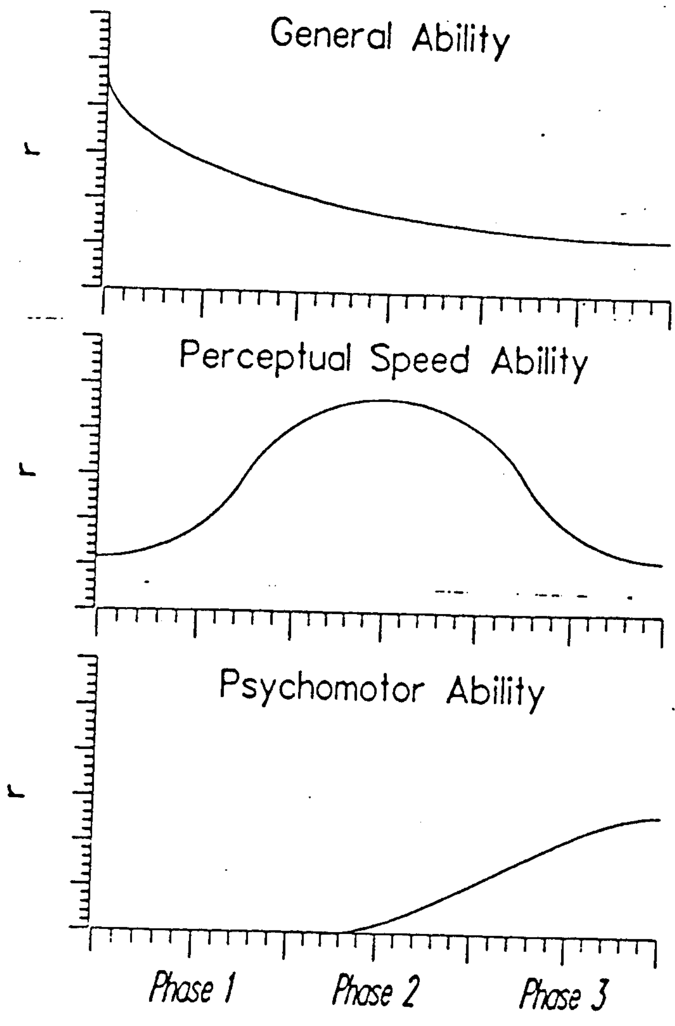

Figure 1: Ackerman's Skill Acquistion Theory
(from "Determinents of Individual Differences During Skill Acquistion: Cognitivie Abilities and Information Processing" by P.L. Ackerman, 1988, *Journal of Expermimental Psychology: General, 117*, p. 294.)

Ackerman hypothesized that general intelligence (general cognitive abilities) is related to performance in the learning phase in that intelligence is the result of acquiring, storing, retreiving, combining, and forming analogies to be able to transfer information and conceptual skills. These are the same processes that are involved in Phase I of skill acquisition. Perceptual speed abilities represent individual differences in the speed in which pattern differences can be identified. It involves simple items that rely on cognitive abilities to a smaller extent. Cognitive abilities become less important than perceptual abilities as the skill becomes automated. At the final phase, psychomotor abilites represent individual differences in performance where performance involves little to no cognitive processing.A noun-pair task was introduced by Ackerman and Woltz (1993) to be used in studying individual differences in skill acquisition. The noun-pair task requires users to indicate if a pair of words matches one of the pairs listed at the top of the screen as quickly as possible (for a sample of the noun-pair display, refer to Appendix C). Performance on this task was found to be positivly correlated with reasoning abilities and is consisdered to be a "propensity to learn".

The task consists of three sessions of 25 blocks with a total of 1350 trials. One feature of this task is that performance can be accomplished without learning; that is, paticipants can look up t o the top of the display to match the noun pair. However, in this task, the noun pairs are the same within each block so that pariticpants could adopt the "short-cut" strategy of memorizing the pairings so that reaction time is reduced.

Ackerman's (1988) theory of skill acquisition has been applied to tasks involving word searching, spatial figures, and choice reaction time. This theory, however, has also been applied to human computer interaction; more specifically, to completing a graphing task using the SigmaPlot graphing task (Schmidt-Nielsen & Ackerman, 1993).

Schmidt-Nielsen and Ackerman (1993) used the SigmaPlot program in their investigation of cognitive and perceptual abilities and their relationship to how individuals interact with the system. The SigmaPlot program is a graphing program that allows statisticians, researchers, etc. to plot data of various types in many different forms (line graphs, bar and pie charts, etc.). The format for this software is similar to other computer applications and uses pull-down menus that can be accessed via the mouse or the alt-key method. The alt-key method operates by the user hitting the alt-key and the appropriate highlighted letter at the top of the screen to pull down that menu. SigmaPlot also offers keyboard shortcuts that allow a user to go directly to a function without pulling down the menu. These shortcuts eliminate a few steps for a given operation. For example, if a user is maneuvering with the mouse and needs to select data to plot, that user is required to go to the word "Plot" at the top of the screen, pull the menu down, go to the choice "Pick data to plot" on the menu, and then select the appropriate location of the data. On the other hand, if users complete the task with the keyboard shortcut, they need only hit the appropriate key (Shift-F3) and select the appropriate location of the data.

The SigmaPlot graphing task (in this experiment) was constructed so that the participant plotted two lines (labeled Degraded and Normal) on four separate graphs; Figure 2 illustrates a completed file for this graphing task.

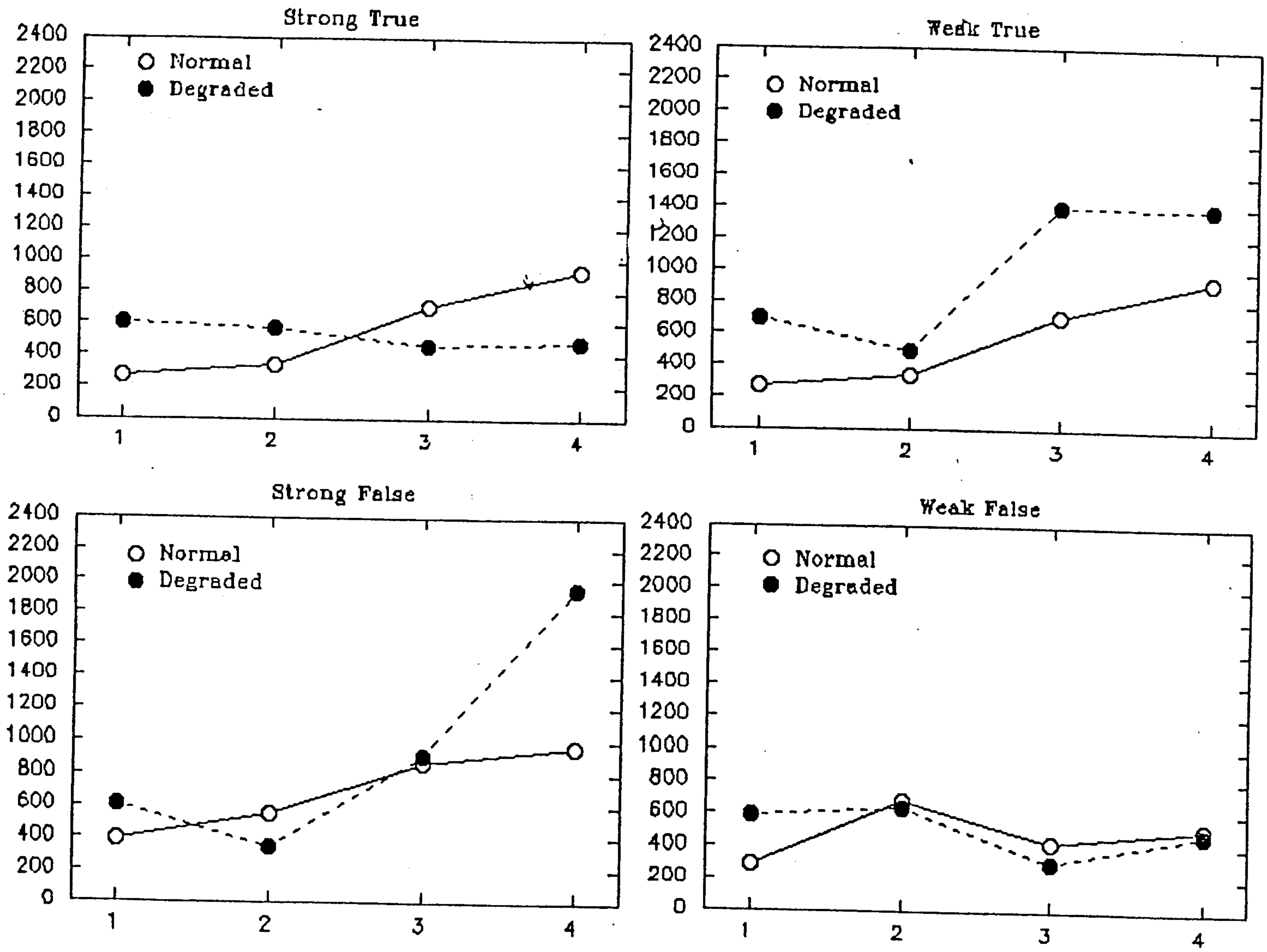

Figure 2: Completed File for the SigmaPlot Graphing Task

Schmidt-Nielsen and Ackerman found that although more efficient methods of interaction exist, they typically involve more mental effort to learn than mouse-driven menus, and some users prefer to use the slower mouse-driven menus (1993). For example, Schmidt-Nielsen and Ackerman classified users into types using two strategies to accomplish the task: those who actively sought out the more efficient methods and those who continued to use the mouse-driven menus which involved minimal mental effort in learning the computer application. They further found that these strategies were correlated with individual differences in cognitive reasoning abilities; and in addition, choice of strategy on the noun-pair task was significantly correlated with the individual's choice of method for performing the SigmaPlot graphing task. Performance on this noun-pair task was significantly correlated with performance on the SigmaPlot graphing task, as was implied by the findings of Ackerman and Woltz (1993) to strategies of performance and noun-pair lookup task. Finally, it was found that many individuals continued to use a look-up strategy for identifying the pairs, in the noun-pair task, as opposed to trying to learn the pairs.

These are only some of the many ways in which individuals differ in their styles and strategies of learning and performing any given task. Much research has been conducted trying to correlate mental abilities with learning and performance strategies (e.g., Ackerman, 1990; Coventry, 1989; Morrison & Noble, 1987; Meng & Patty, 1991; Canino & Cicchell, 1988; MacGregor, et al, 1988; Robertson & Alfano, 1985; Schmidt-Nielsen & Ackerman, 1993).

Field Dependency

Field-dependency is one variable that has been examined extensively as it relates to learning. Field dependency was initially investigated as a perceptual construct (Witkin, Dyk, Faterson, Goodenough, & Karp, 1962). Witkin, et al. found that field dependency affected individuals' perceptions of their body in space. Field dependent individuals were described as those who had a difficult time locating his/her body in space without having external cues available; while, field independent individuals did not have this difficulty and could easily perceive where their body was in space without any external cues.

Later research showed that field dependency is a cognitive style dimension that shows itself in perceptual, intellectual, personality, and social domains (Witkin & Goodenough, 1981). Witkin and Goodenough describe field-independent individuals as those who have cognitive restructuring ability where they are able to perceive a different image by restructuring their initial experience, and whereby they can change the initial organization into something that is more meaningful to them. Field-dependent individuals, on the other hand, adhere to the organization of the perceptual field and cannot easily view a situation in another way. This effect was demonstrated with the Embedded Figures Test that has individuals pick out a simple figure that is embedded in a complex field. Field-independent individuals have little to no difficulty in performing this task. Field-dependent individuals, on the other hand, have great difficulty trying to ignore the complex lines and cannot pick out the simple figure. They cannot ignore the given structure of the complex field and see a more simple image inside the complex figure.

Morrison and Noble (1987) further describe a field-independent individual as one who has the ability to differentiate parts of a confusing situation. These individuals have good analytical and restructuring skills and learn through active exploration of a situation or environment (Witkin et al., 1962; Gardner, Holzman, Klein, Linton, & Spencer, 1959; Coventry, 1989). Field-dependent individuals, on the other hand, tend to react to a situation 'as a whole' and not analyze it (Witkin et al., 1962; Gardner et al., 1959; Coventry, 1989). They tend to rely on external cues (Meng & Patty, 1991) and adopt a passive approach to the environment and problem solving (Coventry, 1989). It is important to note that the concept of field-dependency is not a dichotomy; rather, the abilities of individuals will lie on a continuum (Meng & Patty, 1991).

Evidence of different learning and performance strategies for field dependent and field-independent individuals has been found in research on students using computer assisted instruction (CAI). This research has shown that the computer interface and field dependency can affect how well a student learns. Canino and Cicchell (1988) looked at differences in field dependency and math achievement and found that field-independent students benefit more from CAI than do field-dependent students. With CAI, the students are allowed autonomy in their work by the computerized instruction, which may be more supportive of the learning style of these field-independent students. MacGregor, Shapiro, and Niemiec (1988) also looked at CAI and mathematical learning by comparing two groups, one which received only classroom instruction and one which received classroom instruction with CAI added. The group that did not receive the computer instruction was given additional mathematical problem solving tasks to make the time for each group equivalent. The CAI program in this study provided a more structured learning environment for the students. MacGregor et al., found that this structured learning aided the field-dependent students; field-independent students had greater achievement in the non-computing setting, which was less structured. They also found that students with different cognitive styles learn differently and that this difference is the result of an interaction between cognitive style and the learning environment.

Although these studies may appear to be in conflict with each other, they both support the contention that field-dependent and field-independent individuals may have different learning and performance strategies. The MacGregor et al. (1988) study used a CAI system that was highly structured. Given this structured task, field-dependents performed better. The Canino and Cicchell (1988) study, on the other hand, used a less structured system that had more independent problem solving. Participants were allowed to develop their own strategies in the problem solving task, which was more conducive to the field-independent individual's learning style.

Other studies have manipulated the structure of the CAI program itself (Meng & Patty, 1991). Differences between field-dependent and field-independent students are seen when different levels and types of structure are placed in the learning environment. Further, individuals who lie in the middle of the field-dependency continuum (field-intermediate) perform differently with the different interfaces than either field-dependent or field-independents do.

Contextual organizers have been placed within a CAI system to assess how different organizations affect learning (Meng & Patty, 1991). The contextual organizers were either illustrative (pictorial) or written and they were either presented before or after learning. The illustrative organizers consisted of computer graphic presentations of nonlinguistic, visual stimuli that were placed either before the information to be learned (advance illustrative organizers) or after the information to be learned (post illustrative organizers). The written organizers were computer generated, printed presentations that were placed either prior to the information to be learned (advance written organizers) or after the information to be learned (post written organizers). Meng and Patty found that illustrative advance organizers were most effective for field-dependent individuals whereas field-intermediate individuals were helped most with illustrative postorganizers. Further, they found contextual organizers did not help the performance of field-independent individuals. They suggested this was the result of differing amounts of structure needed by the students. Where the need for structure is based on the students' cognitive style, in that encoding styles and the levels of structure led to differences in learning and remembering (Meng & Patty, 1991). Giving the field-dependent individual advance illustrative organizers, which were developed to be highly structured and concrete, aided them in learning the information. This structure did not help the field-independent individuals, but also did not slow their learning. The field-intermediate participants were aided most by the illustrative postorganizers. The importance of this result lies in the fact that these individuals differed from both the field-dependent and field-independent groups. The authors noted that if the construct of field-dependency had been measured as a dichotomy, the illustrative postorganizers would have been found to be ineffective. However, from this research, it is not clear if there were any differences in performance abilities between field-independent, field-dependent, and field-intermediate individuals. It did show in which environment each group performed best, but it did not show whether or not one group was superior to another with regard to task performance. This study emphasizes that future studies of field dependency must take this intermediate dependent group into consideration.

Performance differences between field independent and dependent individuals have also been found in learning complex games (Robertson & Alfano, 1985). Robertson and Alfano used a game in which a participant had to discover a fixed button-light relationship, and anticipate the sequence, learn which finger to poise over each button and press the correct button before the light came on in order to win the game. By measuring the number of trials to solution or termination, the researchers found that there was an association between more field independence and fewer trials to learn the game. This was attributed to the ability of field-independent individuals to release one's attention from the immediate perceptual field.

Other research has correlated field dependency with performance in a videotex-type task (Morrison & Noble, 1987). Morrison and Noble had participants find international airline flight information and book tickets using a simulated data base and inform a colleague about the plans through electronic mail. They used a factorial design to examine how individuals with different cognitive styles, intelligence, and attitudes towards computers performed using various computer interaction systems. The programs either did or did not have a voice synthesized output (which

echoed the visual output), used either self-defined commands or standard system commands, and had either a friendly or unfriendly interface. The friendly interface allowed users to use abbreviations or corrupt the command string while the unfriendly interface required an exact command input. They found that individuals who scored higher on the Group Embedded Figures Test (GEFT) (more field independent) took less time, progressed farther in the task, and had a less negative attitude about computers. They suggest that the field-independent participants had the ability to overcome contextual confusion and to process information in isolation, which aided them in interaction with the computer system. Although field dependency was not examined as a function of each type of interface, field-independent individuals performed better overall than field-dependent individuals.

Literature on cognitive styles and human computer interaction was reviewed in a project to develop an adaptive computer system (Van Der Veer, Tauber, Waern, & Van Muylwijk, 1985). This review suggested that field-dependent individuals lack the ability to focus on analogies and transfer their solution methods. They predicted that these individuals would need extra help to transfer from one level of the interface to the next.

The research on field dependency suggests that it is not only an important construct in learning tasks, but that it is also an important determinant in human-computer interaction. Field dependency, however, has not been investigated with regard to computer skill acquistion.

Schmidt-Nielsen and Ackerman (1993) tested the skill acquisition theory of Ackerman using a computer task. They found that cognitive abilities were important not only in the begining (learning) phase of the task, but in the later phases as well. These findings, however, were based on small sample. Further, they did not investigate field dependency, an aspect of cognitive style which may be an important factor in performance strategy that may be independent of general reasoning cognitive abilities in skill acquistion and task performance. The present study attempted to replicate and extend the findings of the Schmidt-Nielsen and Ackerman study and further investigate the skill acquistion theory by including the construct of field dependency.

SUMMARY

Research suggests that individuals have different strategies for performing computer tasks. These strategies appear to be consistent and stable over a broad range of tasks. It also appears that field dependency affects cognitive strategies/styles. This has been shown to be true in written paper and pencil tests (Witkin et al., 1981), in CAI (Meng & Patty, 1991; MacGregor et al., 1988; Canino & Cicchell, 1988), and in performance using a computer system (Morrison & Noble, 1987; Coventry, 1989). It is expected that differences in field dependency will be reflected in an individual's choice of a strategy to perform a graphing task using the SigmaPlot program. Further, it is speculated that more field-dependent individuals will stay with the more structured mouse-menu driven system and more field-dependent individuals will adopt the strategy of memorizing the keystroke patterns and may also seek out other ways to use the system.

Hypotheses

The following are hypothesized to be found in the present study:

1. Time to complete a graph in the SigmaPlot program and interaction method (mouse-menu driven, alt-key, function-key system) should be correlated. Users who learn and use more keyboard short-cuts will have faster completion times in all phases of task performance, than those who use more of the mouse-driven menus.

2. Correlations between the psychometric measures of cognitive and perceptual abilities, mean time to complete a graph and number of keyboard strokes will be found. Based on Ackerman's theory (1988), it is expected that the performance difference between high and low groups of cognitive reasoning ability and perceptual speedwill vary across phases of performance, although the high cognitive ability group will have higher performance than the low cognitive ability group for each phase (as was found by Schmidt-Nielsen & Ackerman).

3. Individuals who score higher in the measure of field dependency (more field-independent) will use more of the function keys in all phases of task performance in the SigmaPlot program than will individuals who are more field dependent. This will be reflected by field-independent individuals having a shorter mean time to complete a graph than field-dependent individuals across all phases of task performance. This will correspond to the findings of Schmidt-Nielsen and Ackerman (1993) in that it is a cognitive style attribute that is important to learning and performing any given task.

4. Mean time to complete a graph will be positively correlated with mean time on the noun-pair task performance for all phases. Schmidt-Nielsen and Ackerman (1993) investigated performance on the noun-pair memory test but did not look at mean time to perform the task. Ackerman and Wolz (1993) demonstrated that reaction time in this noun-pair task correlated to reasoning abilities. Therefore, reaction time should have a similar relationship to time to complete a graph in the SigmaPlot task as the cogntive reasoning abilities measures do.

METHOD

Participants:

Ninety-nine George Mason undergraduate students participated in this study. All subjects were novice users of the SigmaPlot software system. Three did not complete the study and their data are not included in the analysis. Of the 96 who completed the experiment, data from 93 were used in the analysis (data from three participants were lost due to equipment problems). The age range of the participants was from 17 to 48 years of age (mean = 20.5). Participants were enrolled in an introductory psychology class and participation fulfilled a class requirement to participate in research.

Materials:

The following tests were given to each participant (see Appendix A). To asses perceptual speed, the Clerical Speed and Accuracy (Bennett, Seashore, & Wesman, 1989) was given, which tested speed of recognition. The Name Comparison (Andrew, Paterson, & Longstaff, 1979); and Number Comparison (Anderson, et al, 1979) were also employed where individuals compare names and numbers, respectively, to identify items that are not the same. To assess cognitive abilities, the following tests were given: Letter Sets and Figure Classification (Ekstrom, French, Harman, & Dermen, 1976) from the ETS kit which requires individuals to identify the rule that makes the groupings of letters and figures, respecitively. The Number Series (Thurstone, 1938) was also used and this test requires the participant to idntify the next number in a series that follows an underlying rule. The last test used to assess cognitive abilities was the Raven Progressive Matrices (Raven, Court, & Raven, 1992) where participants were tested on their ability to perceive abstract relationships between abstract figures by completing sets of figures. The Group Embedded Figures Test (Witkin, Oltman, Raskin, & Karp 1971) was used to assess field dependency where participants identified a simple figure embedded in a complex pattern. The SigmaPlot graphing Phase was videotaped with a VHS recorder using two Sony Handycam cameras to capture the screen and the keyboard separately. At the end of the session, participants were given a memory test of the interaction methods (see. Appendix B).

Design:

Groups were formed based on performance on the individual differences tests. Three groups of cognitive abilities (low, medium, and high), perceptual speed (low, medium, and high) and field dependency (field dependent, field intermediate, and field independent) and two groups of noun-pair performance (fast and slow) were formed. Performance on the SigmaPlot grouping task (time to complete a graph) was then analyzed for the groups. The SigmaPlot session was scored by measuring the time required to complete the first error free graph in each five minute segment. The session ran 100 minutes; this yeilded 20 different time segments for each participant. These 20 segments were placed into groups of five to create four phases of task performance. The first phase (time segments 1-5) was considered to be learning phase that is

equivalent to Phase I in Ackerman's (1988) theory. The second and third phases (time segments 6-10 and 11-15) are representative of Phase II; and the fourth phase (time segments 16-20) are representative of Phase III. It is important to note that psychomotor ability was not measured in the current study and would most likely apply to this fouth phase.

Procedure:

The procedure was based on Schmidt-Nielsen and Ackerman (1993); the participants were required to participate in three sessions. During session 1, participants read and signed informed consent forms and filled out background questionnaires (see Appendix D). Participants who were under the age of 18 (nine subjects were 17) were required to get parental consent before participation.

Session 1:

In the first session, the participants individually performed the SigmaPlot graphing task on which they were required to bring up a data file and create four graphs for each file (see Figure 2). For each graph, they created two plots, one normal and one degraded. As mentioned above, the first error free graph in each five minute segment was measured. Time to complete the graph, the number of mouse clicks, the number of function-key strokes, and the number of alt-key strokes were recorded. Ackerman's theory (1988) does not address errors and Schmidt-Nielsen and Ackerman (1993) did not measure completed graphs with errors; therefore, in order to replicate their findings and relate them to Ackerman's skill acquisition theory, only error-free graphs were scored. To complete the task, participants had to complete the following steps:

1. select a graph (either with the mouse or the keyboard)
2. select a plot (either normal or degraded)
3. go to the data file and select the appropriate data column
4. return back to the graph file (at that time the computer system will draw the plot)
5. select the next plot
6. go to the data file and select the appropriate data column
7. select the next graph

These steps were repeated until all four graphs (one file) were plotted. A total of 52 files were created. This number of graphs was created so that there would be enough files for the participants to work for a total of 100 minutes withoug running out of files. The methods available for completing these steps are shown in Figure 3.

Each participant was trained on one file with two demonstrations; one using the mouse-driven menu system and the other using the both the Alt-Key menu system and the function-key "short-cut" method. After they were trained on the keyboard method (regardless if this was the first or second method trained on), the particpants were told that the experimenter had waited until the screen was refreshed so that the participant could see what would appear on the screen, but that in normal use of the keyboard they (the participant) could work ahead of the screen and in effect complete an entire graph without seeing the screen. Demonstrations of the two methods of interaction were counter-balanced across participants. Participants then had two practice

graphs before beginning graphs of remaining files. The method of interaction the participant chose to use during the practice trials was noted by the experimenter.

Action	Mouse menus	Alt-key menus	Function Keys
Select graph	click on graph		
Choose graph	OR Graph menu click choice	Alt G S,# OR arrow, enter	ctrl-F1 G, enter, arrow, enter, O
Select plot Choose plot	Plot menu click choice,	Alt-P, S # OR arrow, enter	shift-F1 P, arrow, enter, O
Select data worksheet column	Plot menu click worksheet click col., esc.	Alt-P, P w arrow, enter, esc.	shift-F3
Select plot Choose plot	Plot menu click choice,	Alt-P, S # OR arrow, enter	shift-F1 P, arrow, enter, O
Select data worksheet choose column	Plot menu click worksheet click col., esc.	Alt-P, P w arrow, enter, esc.	shift-F3
Others			
6) Save	File menu	Alt-F, S	ctrl-S
*7) Zoom	View menu	Alt-V, Z or O	ctrl-Z
-) Print	File menu	Alt-F, H	F8
8) Open File.	File menu	Alt-F, O	F2
Select File	click file, click ok OR double click file	Type filename, enter	

Selections (header spanning Mouse menus, Alt-key menus, Function Keys)

You can use either typing or mouse to choose things when using the function keys.

In pop-up boxes, you can choose things by typing the highlighted letter key.

To cancel a box you don't want, click Cancel or type C.

Figure 3: Three Interaction Methods for the SigmaPlot Graphing Task

The participants worked on the graphing task for 50 minutes and was then given a 10 minute break. After the break, the participants again worked for 50 minutes. The participants were videotaped and these tapes were used for later analysis. At the end of the session, the participants took a memory test of the different ways they can interact with the system. The participants were not informed that they would be taking a test at the end of the session.

Session 2:

In the second session, participants individually performed the noun-pair lookup task. The task was divided into three sessions with 25 blocks in each session, totalling 75 blocks. Between each block there was a five minute break. There were 18 trials in each block, yielding a total of 1350 trials. Performance on this task lasted from 45 to 90 minutes, depending on the speed of response from the participant.

All instructions for the task were given to the participant by the computer. The noun-pair task had ten noun pairs (i.e.: ceiling - hill) displayed horizontally across the top of the computer screen (see Appendix C). The nouns pairs were the same throughout the task; however, their placement along the top of the screen was different for each trial. This enabled the participants to learn the noun pairs but also required some scanning time for those who did not learn/memorize the noun pairs. In the middle of the screen, a noun pair was displayed that may or may not have been one of the noun-pairs at the top. The participant was to respond whether or not the noun-pair in the center of the screen was represented on the top of the screen by hitting the "1" key if it was a noun pair and a "2" if it was not a noun pair. Time to complete this task was taken by the computer for each noun-pair trial. At the end of the task, a memory test was given to the particant that asked if a displayed pair was one of the noun pairs they had encountered during the task. During this memory test, none of the noun pairs were displayed on the top of the screen. The participants were not aware that they would be taking the memory test at the end of this session.

Session 3

During session three, the participants performed tests of cognitive abilities, perceptual speed ability, and field dependency. This session was run in groups of no more than 20 participants per group. All groups performed the tests in the following order:

1. Number Comparison
2. Name Comparison
3. Differential Aptitudes Test
4. Letter Sets

<10 Minute Break>

5. Number Series
6. Figure Classification
7. Group Embedded Figures Test
8. Raven's Progressive Matrices.

The total time to complete the tests was approximately 2 hours (this time varied because the Raven's Progressive Matrices is not a timed test).

RESULTS

The videotapes of the SigmaPlot sessions were analyzed by two independent raters. Time to complete a graph, number of mouse actions, alt-key actions, and function key actions were recorded for the first error-free graph in each five minute time frame. This yielded a total of 20 time segments for each participant. The average time to complete the graph over the 20 segments was used in multiple regressions. Each participant's number of keyboard and mouse actions was graphed. Based on time segments 6-20 (the first five segments were not used in the grouping because here the participants may be exploring the system and have not decided on a particular strategy) the participants were classified into one of three interaction strategy groups: mouse only, keyboard only, and mix of mouse and keyboard. The following criteria for keyboard strategy, mouse strategy, and mix strategy groups was formulated:

1. keyboard strategy - here the participant mainly used the keyboard strategies (either alt-key or function-key) to complete the task. Individuals were also placed in this group if they used the mouse only to select the graph. This criterion was adopted because the user only used the mouse once; it was used to start off the task and not in the middle steps of completing the graph. Individuals were also placed in this group if they attempted to use the mouse less than three times throughout the 20 segments.

2. mouse strategy - these participants mainly used the mouse to interact with the system. Again, if the participant used the keyboard less than three times throughout the graphing task, they were placed in this group.

3. mix strategy - these participants actively used both the mouse and the keyboard to complete the graphs. The proportion of mouse vs. keyboard varied between subjects from approximately a 50/50 split of the keyboard and mouse to favoring either the keyboard or mouse and only having a few *consistent* uses of the opposite method.

Interaction Strategy

GOMS (Card, Moran, and Newell, 1983) analysis (goals, operators, methods, selection rules) is based on human information processing and goal guided behavior which uses operators to work toward the goal where the operators form methods which the human selects for a given circumstance. This theory has been used to formulate a Keystroke-Level Model which allows researchers to make predictions about the time to complete a computer task based on the number of keystrokes, mouse action, and processing time of the human operator and the computer.

In the present study, the GOMS analysis was developed to predict time to complete a graph for each of the pure interaction methods in the SigmaPlot graphing task: mouse only, alt-key only, and function-key only. The GOMS analysis prediction was compared to the actual mean times; the results of the GOMS analysis suggests that the hypothesis that the mouse-menu driven method of interaction would be slower than either of the keyboard methods (see Table 1.)

is supported (statistical analyses were also computed and are given below). Included in the GOMS analysis was a predicted time for the optimal path using a mix of menu and keyboard commands (see Table 1), however, no participant used the optimal path in completing the graph. Even though the actual times are not the same as the predicted times, they are in the direction predicted by the model.

Table 1: Predicted GOMS Time and Actual Completion Time

Strategy	Time(sec)	
	Predicted by GOMS	Actual Mean Time
Mouse Only	34.0	33.9
Alt-Key Only	15.2	23.6
Function-Key Only	16.7	38.45*
Optimal Path	14.95	N/A

* This mean is based on one participant.

To assess if time to complete a graph was dependent on the interaction style chosen, a 3x4 mixed factor ANOVA was computed. Results showed that the main effects of interaction strategy (1=mouse, 2=keyboard, 3=mix) and time (phase 1, which is the learning phase; phase 2; phase 3; and phase 4) were significant, $F(2,87)=22.02$, $p<.0001$ and $F(3,261)=127.76$, $p<.000$, respectively; and that the interaction between group and time was significant, $F(6,261)=12.83$, $p<.0001$. Means are given in Table 2. Post hoc t-tests revealed that mouse users were significantly slower than keyboard users at phase 2, $t(65)=4.37$, $p<.0001$; phase 3, $t(65)=3.66$, $p<.0001$, and phase 4, $t(65)=6.44$, $p<.0001$ and significantly slower than mixed interaction users throughout all phases of task performance phase 1, $t(71)=2.31$, $p=.024$; phase 2, $t(71)=4.87$, $p<.0001$; phase 3, $t(71)=4.20$, $p<.0001$; and phase 4, $t(71)=4.87$, $p<.0001$. Finally, it was found

that the keyboard and mixed interaction groups did not significantly differ across any of the phases of task performance.

Table 2: Mean Completion Time (seconds) as a Function of Interaction Strategy

Time	Interaction Strategy			Phase
	Mouse	Keyboard	Mix	
1	42	38	36	39
2	38	29	27	31
3	36	25	23	28
4	34	23	24	27
Interaction Method	38	29	27	

These findings support the prediction that time to complete a graph is dependent upon the interaction strategy used (see Figures 1-5); however, this dependency changes over time. In the early learning stages of performance, all types of interaction strategies require a good deal of time to complete a graph. Once the application is learned, however, time to complete a graph does change as a function of the interaction strategy selected.

Examples of users' strategies and the pattern of mouse clicks and key strokes are shown for the mouse, alt-key, function-key, and mixed strategies in Figures 4a-7a. Time to complete a graph for each of these users are illustrated in Figures 4b-7b. Illustrated in Figures 4a and 4b is one individual who is representative of the mouse only group. These figures shows that the user did in fact only use the mouse strategy and that the time to complete the graph decreased over the time phases. However, this decrease in time to complete a graph is not as large of a decrease as it

is for the keyboard or mixed strategy groups. Figures 5a, 5b and 6a, 6b illustrate individuals who are representative of the keyboard strategy group (alt-key and function-key users, respectively). The 5b and 6b figures clearly show the dramatic decrease in time to complete a graph for the keyboard strategy group. Figures 7a and 7b illustrate an individual who is representative of the mixed strategy group. Here again the large decrease in time to complete a graph can be clearly seen in Figure 7b. Figure 8 compares each group's mean time to complete a graph. An interesting note is that many of the mouse strategy users did not fluctute in their use of the mouse. They chose the mouse strategy in the beginning of the task and continued to use only that method. Further, many of the mouse users did not change how they used the mouse. The number of mouse clicks and the procedure for completing the graph went unchanged (although it is possible to complete the graph in more than one way even within in each interaction strategy type) throughout the session.

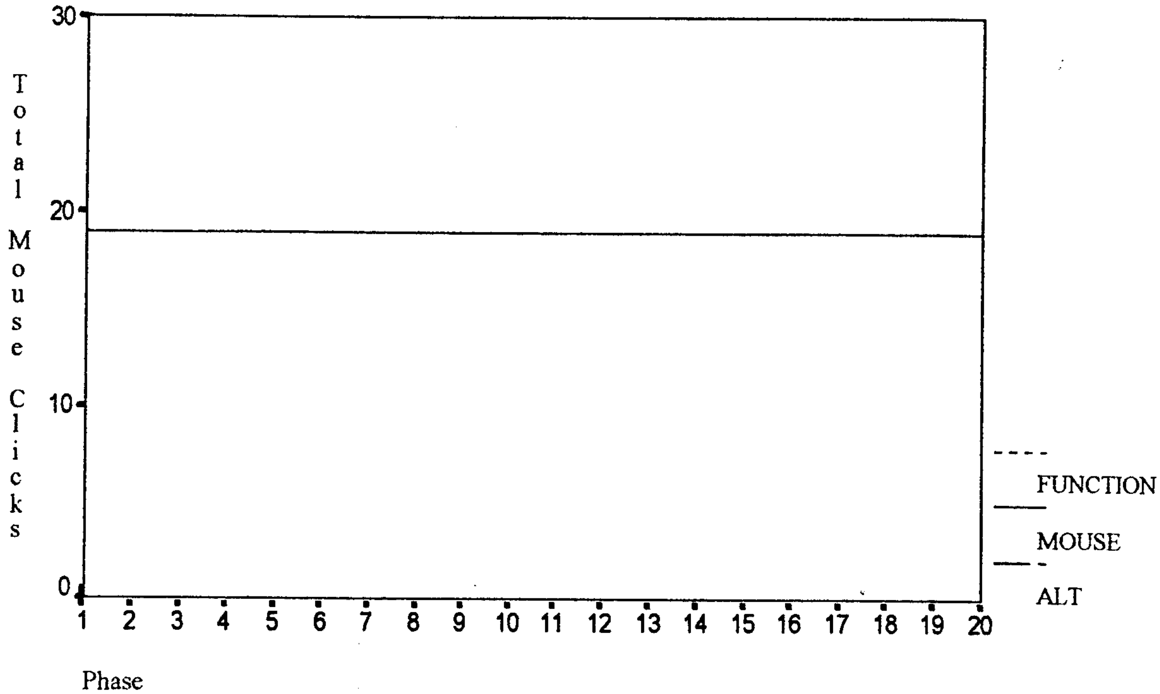

Figure 4a: Number of Mouse Clicks as a Function of Phase

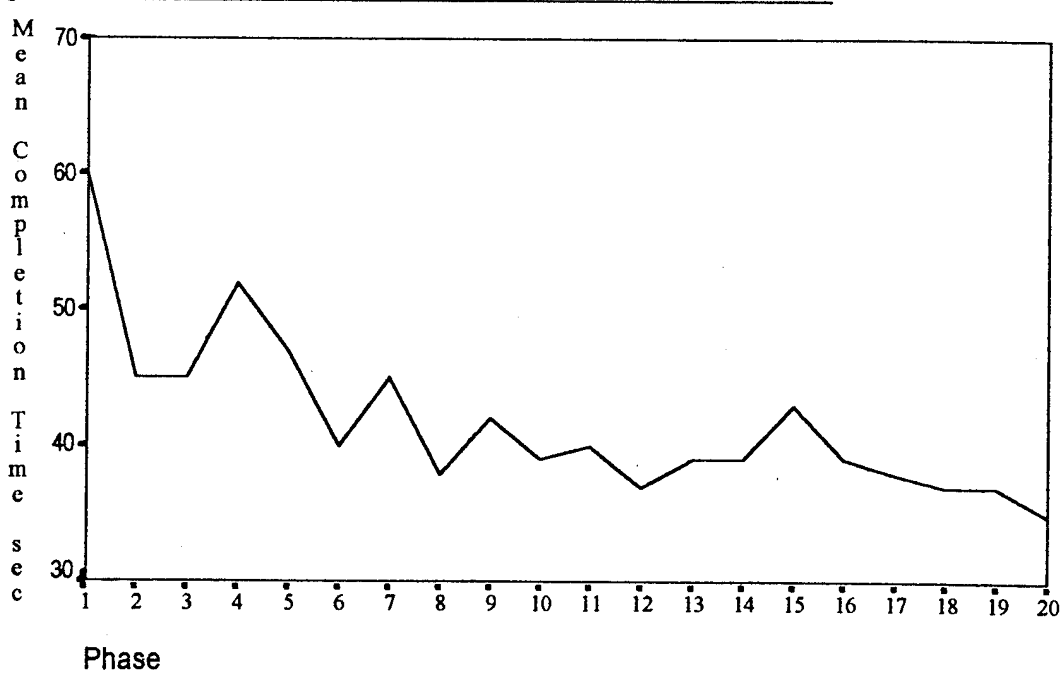

Figure 4b: Mean Completion Time as a Function of Phase

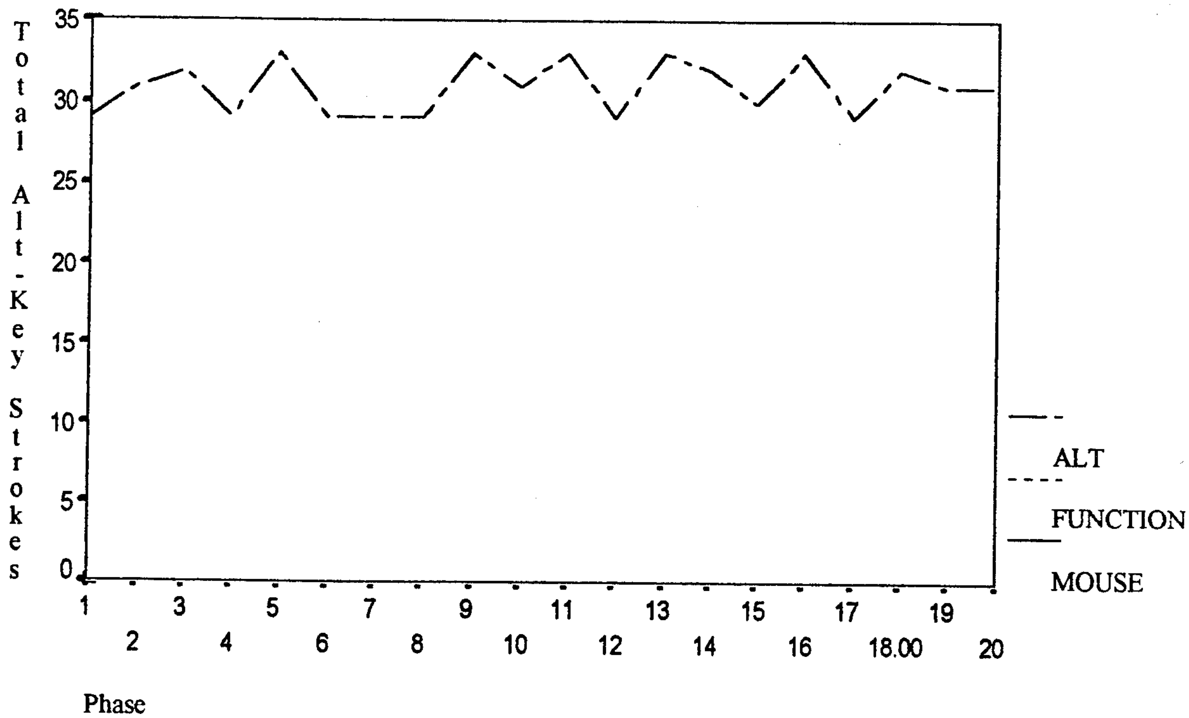

Figure 5a: Number of Alt-Key Strokes as a Function of Phase

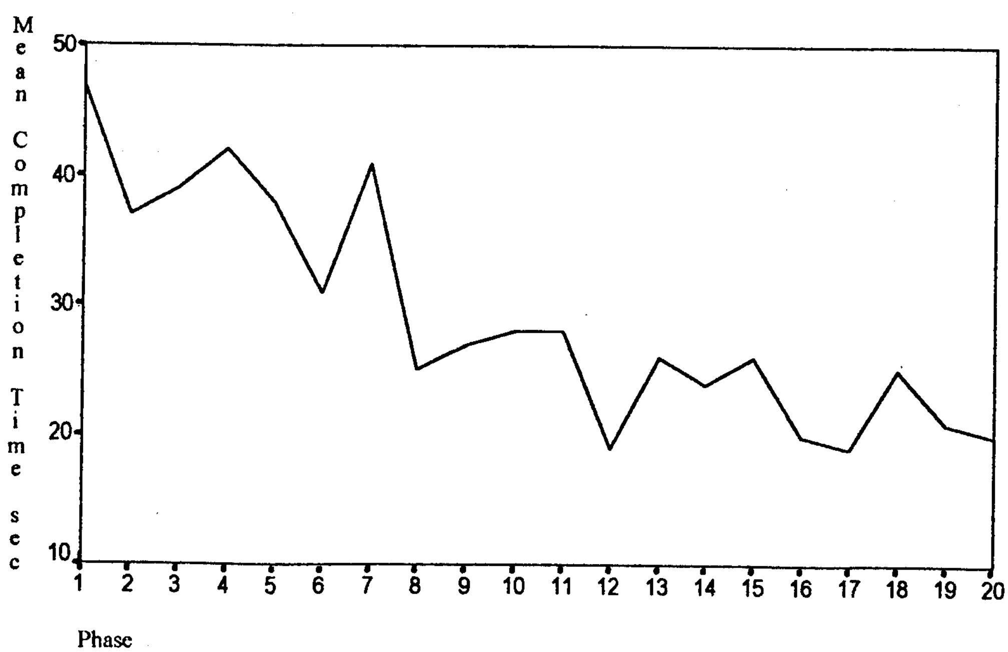

Figure 5b. Mean Completion Time for an Alt-Key User as a Function of Phase

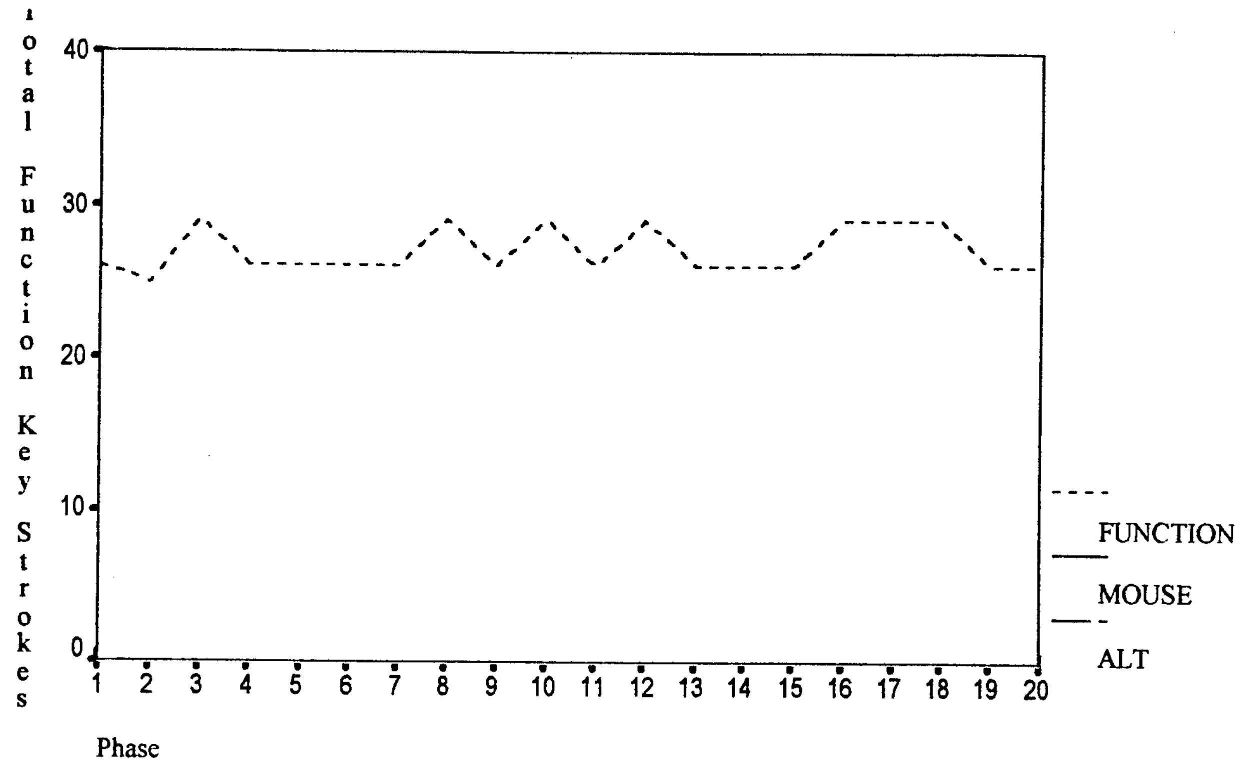

Figure 6a: Number of Function_Key Strokes as a Function of Phase

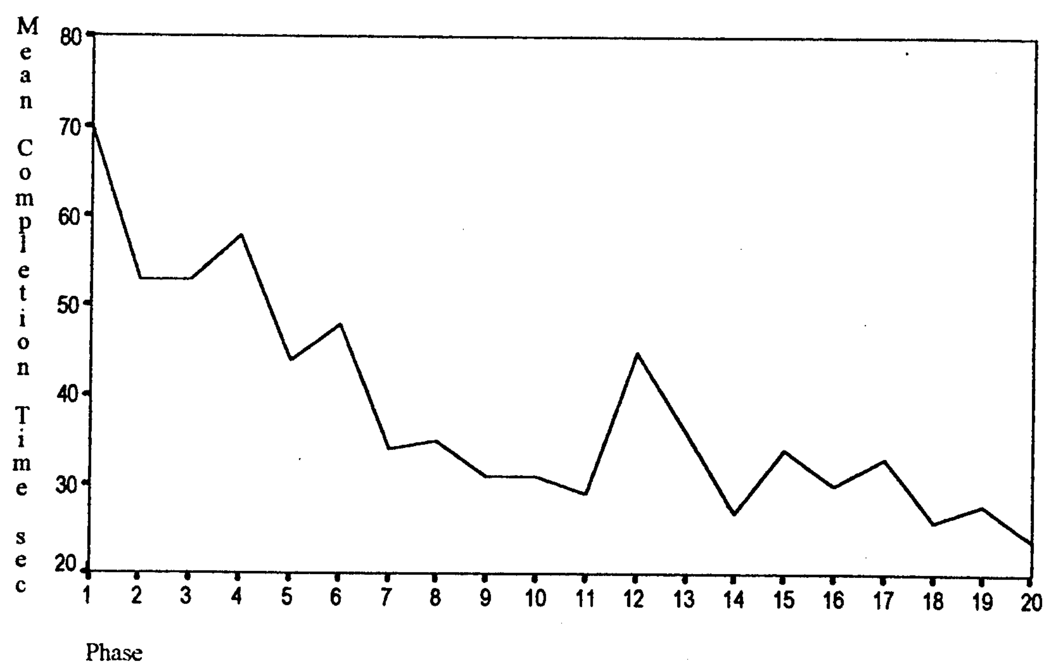

Figure 6b: Mean Completion Time for a Function-Key User as a Function of Phase

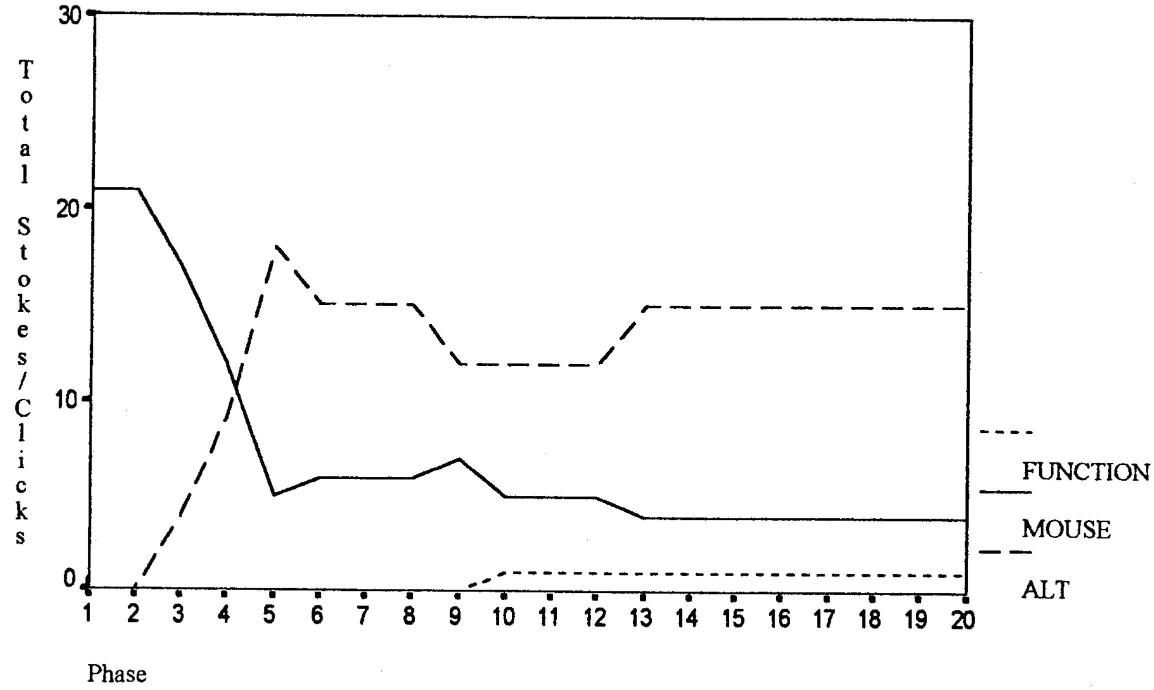

Figure 7a: Total Mouse/Alt-Key/Function-Key Movements as a Function of Phase

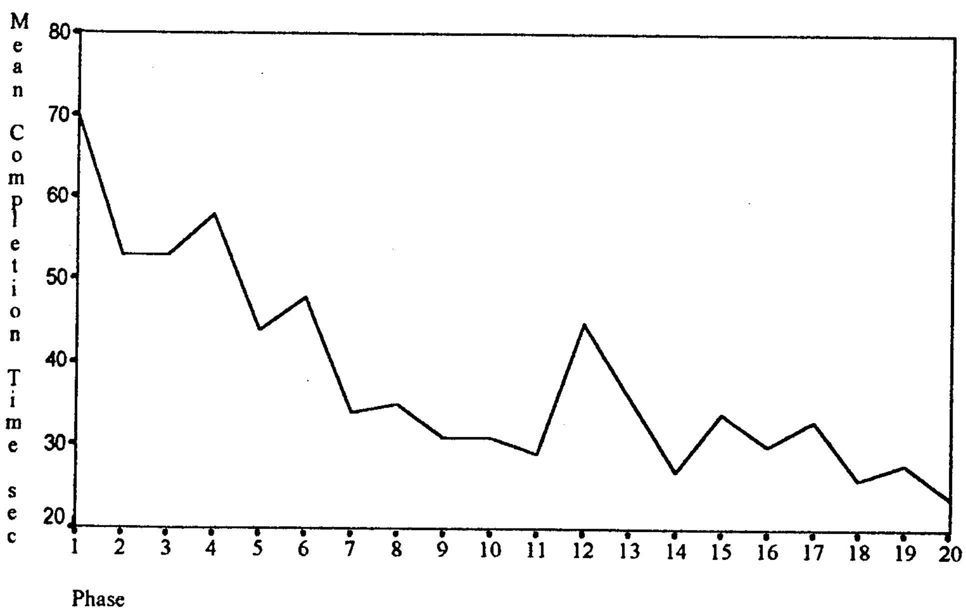

Figure 7b: Mean Completion Time for a Mix-Interaction User as a Function of Phase

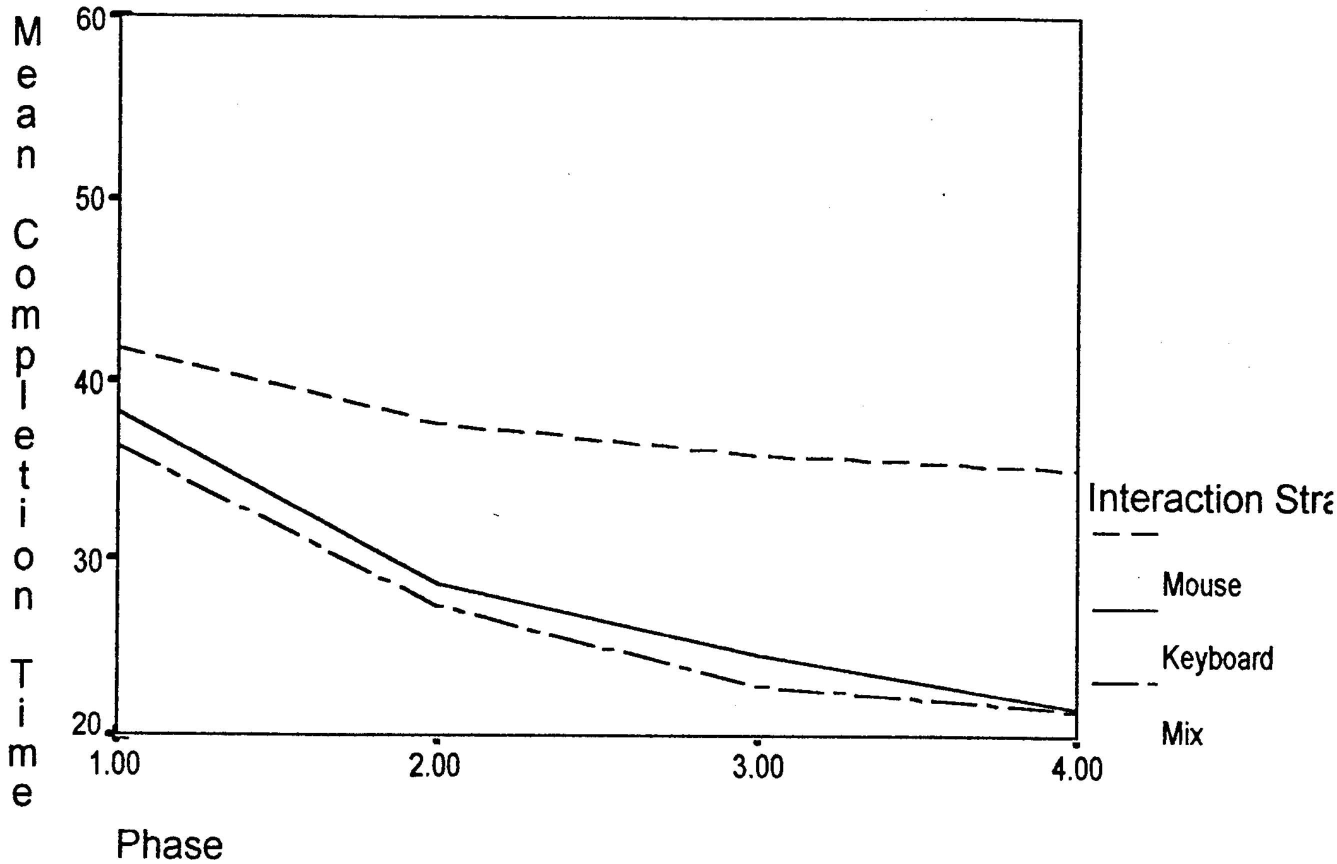

Figure 8: Mean Time to Complete a Graph as a Function of Time and Interaction Stragegy

Cognitive Reasoning Abilities and Perceptual Speed

Pearson product correlations were computed between the individual tests of cognitive ability. No significant correlations between any of the cognitive ability tests were found. Pearson product correlations were also computed between these cognitive measures and overall mean time to complete a graph. The Raven's test was found to have the highest correlation with overall mean time to complete a graph and was thus chosen to assess cognitive ability.

Pearson product correlations were also computed between the individual tests of perceptual speed scores. No significant correlations were found between the tests. Overall mean time to complete a graph and the individual tests of perceptual speed were correlated using Pearson Product Correlations. The Differential Aptitudes test was found to have the highest correlation with mean time to complete a graph and was chosen to assess perceptual speed.

To assess the hypothesis that there is a relationship between psychometric measures of cognitive ability and perceptual speed, the effects of basic cognitive ability and perceptual speed on time taken to complete a graph were investigated. Participants were classified into three groups (low, medium, high) for each dimension of cognitive ability and perceptual speed. Separate mixed 3x4 ANOVAs were calculated for cognitive ability and perceptual speed (1=low; 2=medium; 3=high) on time to complete a graph (phase 1; phase 2; phase 3; phase 4).

For the cognitive ability measure, there were significant main effects of groups and time ($F(2,87)=5.97$, $p=.004$; $F(3,261)=68.58$, $p<.0001$) on overall mean time to complete a graph (see figure 9); interactions between group and time were not significant. Post hoc t-tests revealed that individuals who scored lower on cognitive ability were significantly slower than those who scored higher on cognitive ability level for phase 1 ($t(54)=4.40$, $p<.0001$), phase 2 ($t(54)=3.92$, $p<.0001$), and phase 3 ($t(54)=4.01$, $p<.0001$). Post-hoc Tukey-Kramer tests found that individuals who scored lower on cognitive ability were significantly slower than those who score in the middle level for phase 1 $qT(87)=12.0791$, $p=.05$. The mean time for completion for individuals in the low group was 51.3 seconds and the middle group mean was 39.2 second (see Table 3).

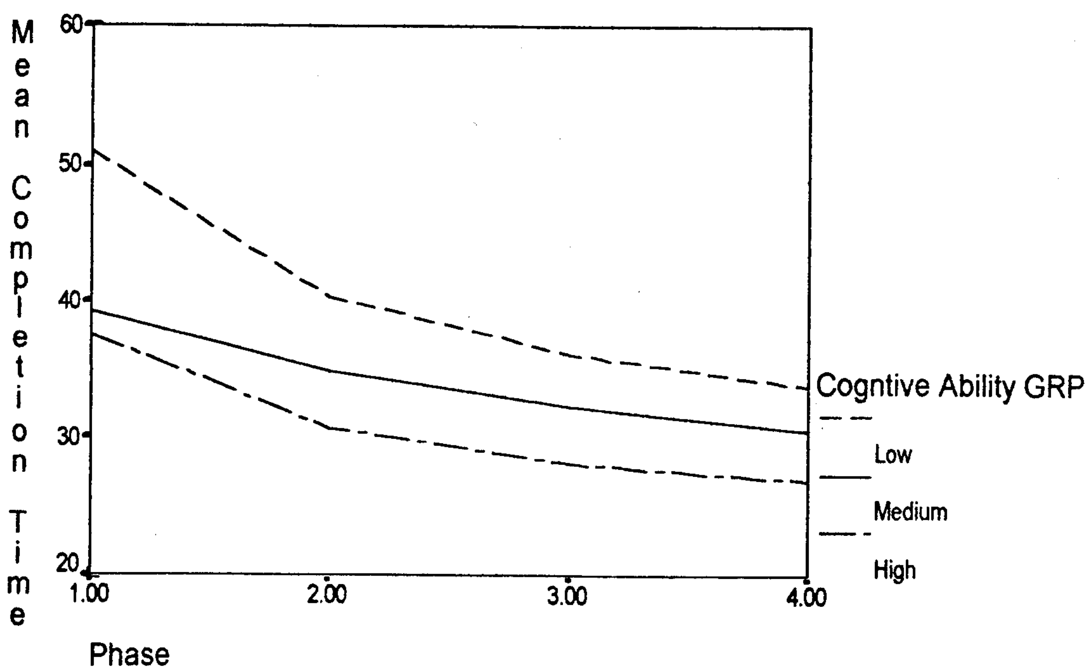

Figure 9: Mean Time to Complete a Graph as a Function of Time and Cognitive Abilities

Table 3. Mean Completion Times for Cognitive Ability Group by Phase

Group	Phase				
	1	2	3	4	
High	37.4	30.7	28.3	27.8	31
Medium	39.2	34.8	32.5	30.1	34.1
Low	51.3	40.4	36.1	33.1	40.2
	42.6	35.3	32.3	30.3	

The mixed (3x4) analysis of variance for perceptual speed and time also showed significant main effects for perceptual speed ($F(2,87)=3.56$, $p=.03$) and for time ($F(3,261)=72.53$), but not significant interactions between time and perceptual speed (see figure 10). Post hoc t-tests revealed that those who have lower scores on perceptual speed have significantly slower times to complete a graph than those who are in the high group of perceptual speed for phase 2 ($t(39)=2.51$, $p=.016$), phase 3 ($t(39)=2.30$, $p=.027$), and phase 4 ($t(39)=2.49$, $p=.017$); while phase 1 approaches significance ($t(39)=1.97$, $p=.055$). Post-hoc Tukey-Kramer tests found no other significant differences. For mean time to complete a graph as a function of perceptual speed and phase, see Table 4.

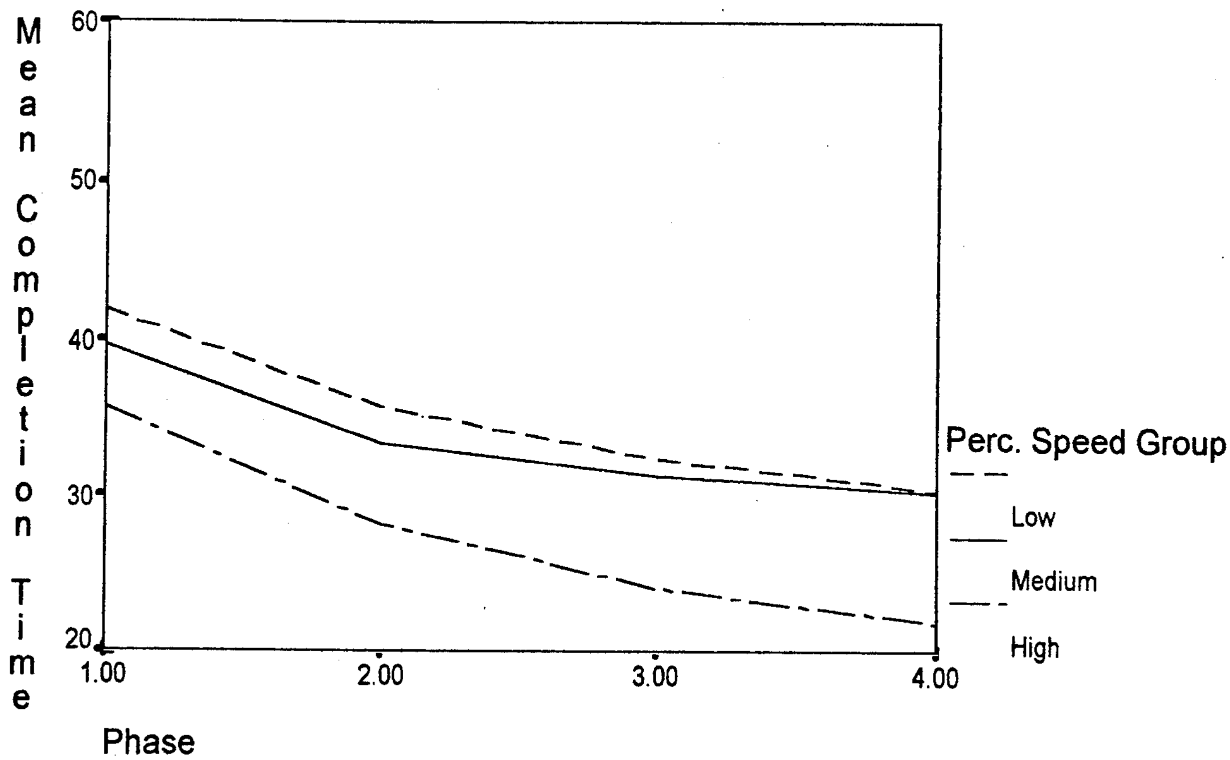

Figure 10: Mean Time to Complete a Graph as a Function of Perceptual Speed

Table 4. Mean Completion Times for Perceptual Speed Group by Phase

Group	Phase				
	1	2	3	4	
High	35.7	28.1	24.6	22.5	27.7
Medium	39.7	33.4	31.6	30.8	33.9
Low	41.9	35.8	32.5	29.8	35
	39.1	32.4	29.6	27.6	

Mixed 2x4 ANOVAs for noun-pair task performance (fast and slow) and time (phase 1; phase 2; phase 3; and phase 4) found significant relationships for noun-pair task, $\underline{F}(1,88)=4.46$, $\underline{p}=.037$ and phase, $\underline{F}(3,264)=83.87$; but no significant interactions were found (see figure 11). Post hoc t-tests showed that those who are faster in the noun-pair task are significantly faster in the graphing task for phase 1, $\underline{t}(88)=-2.10$, $\underline{p}=.039$; phase 2, $\underline{t}(88)=-2.25$, $\underline{p}=.027$; and phase 3, $\underline{t}(88)=-2.37$, $\underline{p}=.02$. These findings are similar to what was found for the cognitive abilities dimension. For mean time to complete a graph as a function of noun-pair group and phase, see Table 5.

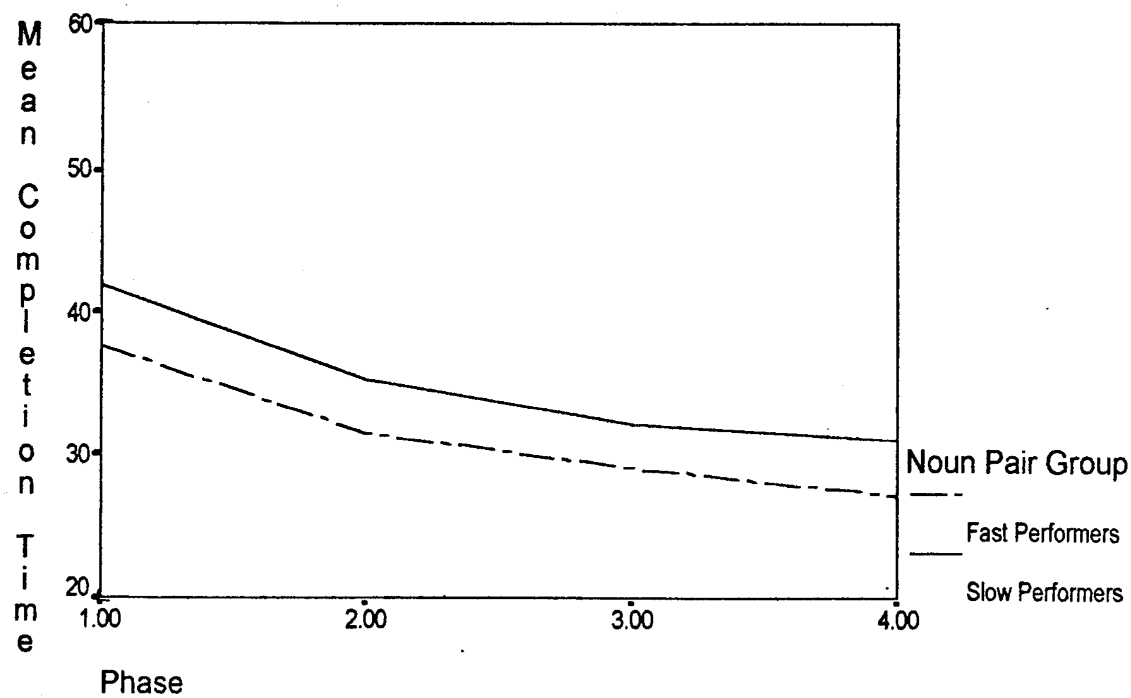

Figure 11: Mean Time to Complete a Graph as a Function of Time and Noun-Pair Performance Group

Table 5. Mean Completion Times for Noun Pair Group by Phase

Group	Phase				
	1	2	3	4	
Fast	37.7	31.4	29.3	27.9	31.6
Slow	41.9	35.3	32.4	30.7	35.1
	39.8	33.4	30.9	29.3	

Field Dependency

The hypothesis that the field independent group would have faster times to complete a graph than the field dependent group was tested with a 3x4 mixed analysis of variance for field dependency and time (see figure 12). Significant main effects for time, $F(3,261)=77.61$, $p<.001$; and field dependency, $F(2,87)=3.91$, $p=.024$ were found. Planned comparison t-tests revealed that those who are field dependent have a significantly higher mean time to complete a graph than those who are field independent for phase 1, $t(62)=2.99$, $p=.004$; phase 2, $t(62)=2.92$, $p=.005$, and for phase 3 $t(62)=2.96$, $p=.004$). Post-hoc Tukey- Kramer tests found no significant differences between field intermediates and field independents and between field intermediates and field dependents. For mean time to complete a graph as a function of field dependency and phase, see Table 6.

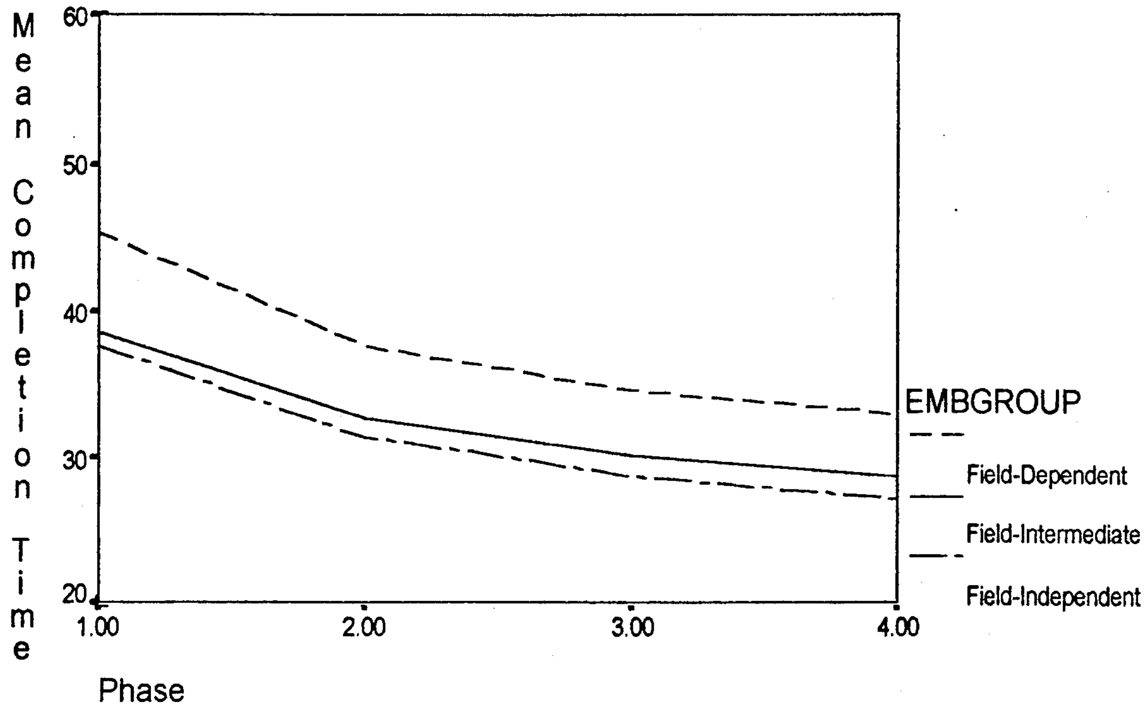

Figure 12: Mean Time to Complete a Graph as a Function of Time and Field-Dependency

Table 6. Mean Completion Times for Field Dependency by Phase

Group	Phase				
	1	2	3	4	
Field Dependent	45.4	37.7	35.1	32.0	37.6
Field Intermed.	38.5	32.6	29.9	29.4	32.6
Field Independ	37.6	31.6	29.1	27.9	31.5
	40.5	34	31.4	29.8	

Group Cross Tabulation

Users were categorized as a function of cognitive ability and interaction strategy used (see Table 7) and chi-squares were performed to determine if those who are higher in cognitive ability are using the faster (keyboard and mix method) strategies. For cognitive ability, the chi-square was not significant χ^2 (4)=.68, p=.95).

Table 7: Group Membership for Cognitive Ability and Interaction Strategy (observed and expected).

Interaction strategy group	Cognitive Ability		
	Low	Medium	High
Mouse	7(6.1)	2(2.8)	2(2.1)
Keyboard	18(18.9)	10(8.7)	6(6.4)
Mix	25(25.0)	11(11.5)	9(8.5)

A similar categorization was done for perceptual speed and interaction strategy (see Table 8). The chi-square was not significant (χ^2=8.28, p=.08). This suggests that there is an even distribution of the interaction strategy groups across the cognitive abilities and perceptual speed groups. A Chi-square performed on the categorization by field dependency and interaction

Table 8. Group Membership for Perceptual Speed and Interaction Strategy (observed and expected).

Interaction strategy group	Perceptual Speed		
	Low	Medium	High
Mouse	17(15.6)	5(7.2)	6(5.3)
Keyboard	30(27.2)	13(12.5)	6(9.3)
Mix	3(7.2)	5(3.3)	5(2.5)

strategy was not significant (χ^2=.78 p=.94) which suggests that there is an even distribution of the interaction strategy groups across the field dependency groups. This shows that field dependency does not determine what type of interaction method used.

Table 9.Group Membership for Field-Dependency and Interaction Strategy (observed and expected).

Interaction Strategy	Field Dependency		
	Field Dependent	Field Intermediate	Field Independent
Mouse	13 (12.2)	5 (5.6)	4 (4.2)
Keyboard	14 (14.4)	8 (6.6)	4 (4.9)
Mix	23 (23.3)	10 (10.7)	9 (7.9)

Multiple Regression Analysis

To determine what variables can predict time to complete a graph while controlling for the remaining variables, multiple correlations were computed. First, to assess overall mean time to complete a graph (ignoring the phases of task performance) a multiple regression was computed with field dependency, cognitive ability, perceptual speed, mean reaction time on the noun-pair task, interaction strategy, and demographic characteristics (which were measured via the

background questionnaire) of age, years of experience, and gender. Before interaction strategy contrast are entered into the equation, a significant amount of the variance is accounted for (R =.61, R^2=.37, p<.001). When the comparisons are entered, the resulting correlation increases to R =.73, R^2=.53, p<.001 and: the R^2 change = .16, p (of change) <.001. Table 10 shows the significant beta weights for this regression .

Table 10: Significant Beta Weights for Time to Complete a Graph

Variable	Beta	Significance
Years of Experience	-.24	.004
Age	.20	.014
Perceptual Speed	-.18	.028
Mouse vs. Keyboard	.20	.001
Mouse & Keyboard vs. Mix	.35	.000

As predicted, the time to complete a graph is significantly negatively correlated with perceptual speed, where those who score higher on perceptual speed have a lower mean time to complete a graph (β = -.18, t=-2.24, p=.028). The negative relationship predicted for cognitive ability approached significance (β= -.19, t=-1.87, p=.065). Further, before interaction strategy group comparisons are entered, cognitive ability was significant (β =-.328735, t=-2.736, p=.008) which suggests that cognitive abilities and interaction strategy groups are accounting for some similar variance. This analysis further showed that older individuals and those with more years of computer experience completed graphs more quickly. The age dimension should be interpreted with care, however, in that the majority of the participants were between the ages of 18 and 24, which represents a significant restriction of range. The regression also confirms that those who use the mouse-driven menu system are slower at completing a graph than are those who use the keyboard or mixed methods. Those who used the mixed strategies were significantly faster at completing a graph than any other interaction strategy group. Field dependence was correlated

with cognitive ability ($\underline{r}$=.627, $\underline{p}$<.001); but it did not significantly predict mean time to complete a graph when the cognitive ability measure was included in the regression equation. This is consistent with the literature, suggesting that cognitive reasoning ability and field dependency accounts for similar variance in time to complete a graph. It was also predicted that speed of performance on the noun-pair task would be significantly related to time to complete a graph. However, this analysis suggests that field dependence does not contribute uniquely to explaining the variance in the overall time to complete a graph (β=.10, p=.26).

Multiple correlations were also computed for each phase of the task. For phase 1 it was found that $\underline{R}$ =.55, $\underline{R}^2$=.30, p<.001. In this phase the following were found to have a significant weight on the regression:

1. years of computer experience: β=-.28, p=.01; where those who had more computer experience had a faster time to complete a graph;
2. age: β=.20, p=.04; where those who are older had a faster time to complete a graph (again because of the restriction of range interpretation is unwarrented); and
3. cognitive abilities: β=-.26, p=.04; where those who have higher scores of cognitive abilites have faster times to complete a graph.

For phase 2, it was found that $\underline{R}$ =.71, $\underline{R}^2$=.50, p<.001. The following were found to have significant beta weights in this regression:

1. years of computer experience: : β=-.255, p=.01; this variable is unchanged from phase 1; in the second phase of task performance, those who have more years of computer experience have faster times to complete a graph;
2. age: : β=21, p=.01; again this relationship should not be interpreted;
3. perceptual speed: : β=-.19, p=.03; as expected, in phase 2 perceptual speed is significant where those who have faster times to complete a graph score higher in perceptual speed abilites;
4. mouse vs keyboard contrast: : β=.19, p=.02; in phase 2, time to complete a graph differences are significant between mouse and keyboard users where those who use the keyboard have faster times to complete a graph than those who use the mouse;
5. mouse and keyboard vs. mix strategy contrast: β=.32, p=.01; this contrast also is significant in phase 2 which suggests that those who use the mix strategies have the fastest time to complete a graph;
6. cognitive abilities: : β=-.20, p=.06; this variable approaches significance at this phase which shows that as the individuals learn the task (acquire the skill) cognitive abilities have a weaker relationship to task performance.

The Phase 3 multiple regression equation showed $\underline{R}$ =.76, $\underline{R}^2$=.58, p<.001. The following variables had significant beta weights at phase 3 of task performance:

1. years of computer experience: : β=-.20, p=.01; this variable is unchanged from phase 1 and 2. In the third phase of task performance, those who have more years of computer experience have faster times to complete a graph;

2. age: : β=.18, p=.03; again this relationship should not be interpreted;
3. perceptual speed: : β=-.16, p=.05; as expected, in phase 3 perceptual speed is still significant where those who have faster times to complete a graph score higher in perceptual speed abilites;
4. mouse vs keyboard contrast: : β=.25, p<.001; in phase 3, time to complete a graph differences between mouse and keyboard are significant and somewhat stronger than in phase 2; again, those who use the keyboard have faster times to complete a graph than those who use the mouse;
5. mouse and keyboard vs. mix strategy contrast: β=.43, p<.001; this contrast also is significant in phase 3; again, those who use the mixed strategy have the fastest time to complete a graph.

nally, in phase 4, the multiple regression equation yielded $\underline{R}$ =.68, $\underline{R}^2$=.46, p<.001. The following beta weights were found to be significant in phase 4:

1. age: β=.18, p=.04; however, this variable is not interpretable;
2. mouse and keyboard vs. mix strategy contrast: β=.46, p<.001; this contrast is significant in phase 4, where those who use the mixed strategies have significantly faster times to complete a graph than either those who use the mouse or those who use the keyboard.

In phase 4, the perceptual speed variable does not add a significant unique contribution to the regression; years of computer experience also is not a significant variable. It appears that in phase 4, the main determinent of task performance is the type of strategy chosen. Before the constrasts of mouse vs. keyboard and mouse and keyboard vs. mix strategy are entered, the following variables were found to be significant: years of computer experience (β=-.24, p=.02); gender (β=-.22, p=.04, where males have faster time to complete a graph than females); and perceptual speed (β=-.23, p=.03). These variables are not significant when the contrast between strategies is entered. This suggests that these variables and the grouping (between the mouse, keyboard, and mix strategy) variable are accounting for similar varaince in time to complete a graph. This lends support to the contention that there is a significant relationship between perceptual speed and interaction strategy. The variables that are important to time to complete a graph change over the phases. Table 12 illustrates the changes in value of the beta weights over the four phases.

Table 11: Betas for Regression Equations for Each Phase

Variable	Phase 1		Phase 2		Phase 3		Phase 4	
	Beta	**Signif**	**Beta**	**Signif**	**Beta**	**Sigif**	**Beta**	**Signif**
Yrs of Exp	-.28	.01	-.26	.001	-.20	.01	-.13	.13
Age	.20	.04	.21	.01	.18	.03	.18	.04
Cogn. Abilities	-.26	.04	-.20	.06	-.14	.16	-.06	.60
Percept. Speed	-.17	.09	-.19	.03	-.16	.05	-.12	.17
Mouse vs. Keyborad	.08	.41	.19	.02	.25	<.001	-.12	.07
Mouse and Keyboard vs. Mix	.03	.78	.32	<.001	.43	<.001	.46	<.001

DISCUSSION

The present study shows that the hypothesis that individual differences of cognitive ability, perceptual speed, field dependency, and noun-pair task performance are associatied with user performance during the SigmaPlot graphing task was supported. These individual differences are related to the interaction method used; and in turn, the interaction method has a relationship to task performance where those who use the mouse have the slowest time to complete a graph and those who use the mixed method have the fastest times to complete a graph. This suggests that those who measure in the high groups of cognitive ability and perceptual speed and those who are field independent are using the keyboard or mixed method strategy to complete the graphs.

It is interesting to note that many participants chose to use the mouse method for performaning the task. Futher, it was interesting to note that when an individual choose to use the mouse interaction method, they rarely deviated from this method. Very few of these individuals tried the keyboard sequence even once, nor did they deviate in the pattern of mouse use. Even within the mouse, there was more than one way to complete a function. These individuals found one way to use the mouse and rarely, if ever, wavered from this pattern. Over the years, the mouse has become a very important input device to computer users. Many individuals rely on the mouse. This is particularly true of those who have very little computer experience, and many of the participants in the study had little to no computer experience. In fact, there may be a relationship between the number of years of computer experience and the interface strategy selected. The present study found that those weith more years of computer experience tended to complete the graphs faster than those with less years of experience. This suggests that thsoe with computer experience choose the more sophisticated methods to completing the graphs. This, in part, supports the contention that computer experience and interaction strategy are related. Future research would need to be conducted to validate this contention.The present findings suggest that those who are higher in perceptual speed and cognitive ability, have more years of experience and use the keyboard or a mixed interaction strategy demonstrate optimal performance. Age was also found to be a determinant of user performance, however, interpretation of this finding is suspect given the restricted age range.

It was hypothesized that the time to complete a graph would be related to the interaction strategy selected by the participant. The findings of the present study are consistent with this hypothesis. It is interesting that it was not the function-key shortcut method that was found to be the fastest, but instead, a mix method strategy of using the mouse and the keyboard was found to yield optimum performance. The GOMS analysis predicted this relationship and the results of the present study support it. However, it is important to note that the mouse only method of interaction yields the slowest performance time, as predicted. This relationship between interaction method and time to complete a graph was found for the second, third, and fourth phase of performance only. The first phase is the learning stage of performance, and during this time, time to complete a graph does not differ much across the groups. This suggests that it does not take individuals more time to learn the keyboard and that in the later phases of performance, those who learned the keyboard are at an advantage over those who did not.

The present study supports Ackerman's theory (Ackerman, 1988) that cognitive ability is important in the beginning stages of learning a task, perceptual speed is important in the middle stages of performance, and psychomotor skills are important in the later stages of task performance. The present findings of cognitive reasoning ability and perceptual speed support this theory. During the first five segments, where the participant is learning the task, time to complete a graph was associated with cognitive reasoning abilities and not perceptual speed. During the skill acquisition and transfer stage, time to complete a graph was dependent upon both cognitive ability and perceptual speed. During skilled task performance (the last five segments), time to complete a graph was dependent only upon perceptual speed. Psychomotor skill was not measured; thus, the present study cannot make any inferences about contribution of individual differences of psychomotor skills to skill acquisition.

These findings; however, are inconsistent with those of Schmidt-Nielsen and Ackerman (1993) who found that cogntive abilities had a significant relationship to time to complete a graph in all phases of task performance. There was a methodological difference between the two studies, where in the Schmidt-Nielsen and Ackerman study participants were told their completion times for each graph as they were completing the task. In the present study, subjects were not given this feedback. It may be that this direct feedback had different motivational influences on the Schmidt-Nielsen participants, where those who have higher cognitive abilites can be pushed to perform at a higher rate than individuals who are lower in cogntive abilies. Again, future research would need to be conducted to assess this theory. Another difference in findings is that the Schmidt-Nielsen and Ackerman study found that perceptual speed was not significant, and in the present study, this was found to have a significant relationship with time to complete a graph; again this is consistent with the Ackerman (1988) skill acquistion theory.

The findings regarding the noun-pair task are consistent with the skill acquistion theory and the results of Ackerman and Woltz's (1993) research. This task appears to be measuring cognitive abilites that, in the present study, account for similar variance as the cogntive reasoning ability measure in the time to complete a graph. Performance on this task was related to the SigmaPlot task performance in phase 1, 2, and 3 but not in phase 4. These results mirror those of the cognitive ability measue which is suggested by the Ackerman (1988) theory to only be important in the initial, learning, stages of task performance.

The results of the present study also support the hypothesis that field dependency is related to user strategy choice in the SigmaPlot graphing task. However, field dependency and cognitive reasoning ability appear to be accounting for similar variance in the time to complete a graph. Further, field-dependency does not predict variance in performance over and above that predicted by the cognitive reasoning ability measure. It would appear that cognitive abilities and field dependency are redundant and when one has information about an individual's cognitive abilities, they also have information about their field dependency.

If only the field dependency is known, however, performance on the SigmaPlot task can be predicted. Therefore, it is a useful dimension to predicting performance during the learning stages, which is consistent with the previous literature on field dependency (Coventry, 1989; Morrison & Noble, 1987; Meng & Patty, 1991; Canino & Cicchell, 1988; MacGregor, Shapiro, & Niemiec; 1988; Robertson & Alfano, 1985).

Limitations to the Study

There were some problems in the present study that may have contributed to the present results. The experimenter was in the room when the participants worked through the SigmaPlot graphing task. The participants did not appear to be motivated to perform the graphing task, much less learn the keyboard shortcuts. This was observed by the participants' excessive slouching, heavy sighs, and shuffling around during the task. Also, some pariticipants asked the experimenters how much time they had left and appeared agitated with the response. Many participants informed the experimenters, after completion of the task, that they did not enjoy the task and thought it was very boring. Further, this task seemed to be a bit trying for the participants and it was noted by the experimenters that the participants lost concentration and became fatigued by the end of the task. A future study that is shorter should be conducted to determine if there were any significant effects of fatigue.

The SigmaPlot graphing software was one where the participants would not need to learn the short cuts because they would not encounter this package again out in the real world. The mouse-driven menu system was easily understood and over half of the participants tested chose to stay with this interaction method. It was suggested to the participants that learning the short cuts would increase their speed performance, however, this was not stated as directly to them as in the Schmidt-Nielsen and Ackerman (1993) study. If this was directly stated, more individuals may have used the keyboard strategies.

Implications

In general, user behavior is partially determined by individual differences. These effects may be even more prominent with software systems where users have a lot of motivation to learn short cuts and optimize performance.

This study demonstrates that designers of software need to take user individual differences into account in designing their systems. This is particularly important for the learning stages. The interface needs to be easily understandable and easy to use in order for an individual to continue working with the system. If an individual is having a difficult time learning and interacting with the software or if the software is too limiting and does not allow for active exploration of different methods to complete a task, that individual may opt to use another program that allows for ease of learning and ease of use. Further, it is important to look at individuals who are at the lower levels of cognitive ability (and field dependency) in that those with lower cognitive ability take longer to perform tasks and may become easily frustrated with

the interface. Making the interface easy to use does not hinder performance of individuals at the higher levels of cognitive ability. So in effect, individuals with lower levels of cognitive abilities will get the needed help in performing the task and individuals with higher levels of cognitive abilities can ignore these extras and still perform the task at an adequate level.

Knowing how individuals learn tasks based on differences in cognitive abilities will help designers in implementing the needed aids. Providing structure that can either be adhered to (by using the mouse) or can be ignored (by using short-cut keys) is one way to provide for users with varying levels of cognitive skills. Future work investigating Ackerman's theory (1988) may provide some answers about expert user's differences that may help software designers design for not only the differences between novice user, but also for the differences between expert users.

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APPENDIX A

Ability Tests and Field Dependency Test

1. Noun-Pair Task (Schmidt-Nielsen & Ackerman, 1993) - This is a test to measure and individual's strategy for determining if a pair of words match one of the pairs listed. This is measured through speed to complete the task. If the participant is slow at identifying the pair, then they are said to be using a look-up strategy and not learning the pairs of words.

2. Clerical Speed and Accuracy (Bennett et al., 1989) - This is a test that uses a speeded recognition task to determine how quickly and accurately and individual can compare and mark simple letter and number combinations.

3. Name Comparison (Andrew, et al., 1979) - These are tests that measure elements of perceptual speed and accuracy required to perform various clerical activities. The participant is required to inspect each pair of names and decide if they are the same. If they are the same, they are to indicate this by putting a check between the two names.

4. Number Comparison (Andrew, et al., 1979) - This is a test of perceptual speed and accuracy. The participant is required to inspect the pair of numbers and indicate if they are the same. If they are not the same, the participant is to put an "X" between them.

5. Letter Sets (Ekstrom et al, 1976) - This is a test of reasoning ability. Five sets of four letters are presented. The participant is required to find the rule which relates four of the sets to each other and to mark the one which does not fit the rule.

6. Figure Classification (Ekstrom et al., 1976) - This is a test of reasoning ability. There will be either 2 or 3 groups of figures, each containing 3 figures. The participant is required to identify the rule that makes these figures alike and assign each test figure to one of the groups.

7. Number Series (Thurstone, 1938) - This is a test of reasoning ability and requires the participant to identify the next number in a series (from a group of five numbers) and to write the appropriate letter for that number.

8. Raven Progressive Matrices (Raven, et al., 1992) - This test measures powers of observation, rational thinking skills and reasoning ability. The participants will be tested on their ability to perceive relationships between abstract figures and to complete sets of figures by utilizing systematic reasoning.

9. Group Embedded Figures Test (Witkin, et al., 1971) - This is a test of an individual's field-dependency. The participant is required to identify a simple form in a complex pattern. They are to trace the form directly over the lines of the complex figure.

APPENDIX B

Memory Test

Date __________ Name ____________________ Participant # _____

Action

	Mouse menus	Alt-key menus	Function Keys
Select graph	________	________	________
Choose graph	________	________	________
Select plot	________	________	________
Choose plot	________	________	
Select data	________	________	________
worksheet	________	________	
column	________	________	
Others			
6) Save	________	________	________
*7) Zoom	________	________	________
-) Print	________	________	________
8) Open File.	________	________	________
Select File	________	________	

Computer experience:	None______	Occasional______	Frequent_____
Type:	Mac______	IBM______	Other______

APPENDIX C

PRESS <SPACE BAR> TO CONTINUE

Volcano	Lake	River	Ocean	Hill	Cliff	Canyon	Rock	Valley
Closet	Attic	Wall	Brick	Roof	Ceiling	Stair	Door	Window

Lake Ceiling ?

Press “1” if YES Press “2” for NO

APPENDIX D

Background Questionnaire

Participant: ________________________________

Age: _____

Gender: _____

Major/Profession: ________________________________

Years of Computer Experience: ______

List five types of computers you have used (e.g., VAX, PC, Mac, AS400, etc...) and the percentage of time you have spent on them:

Computer	Percentage of Time
____________________	__________
____________________	__________
____________________	__________
____________________	__________
____________________	__________

List five applications you commonly use and the percentage of time you spend on them:

Applications	Percentage of Time
____________________	__________
____________________	__________
____________________	__________
____________________	__________
____________________	__________

Do you prefer using the mouse or the keyboard when making selection choices on the computer?

____